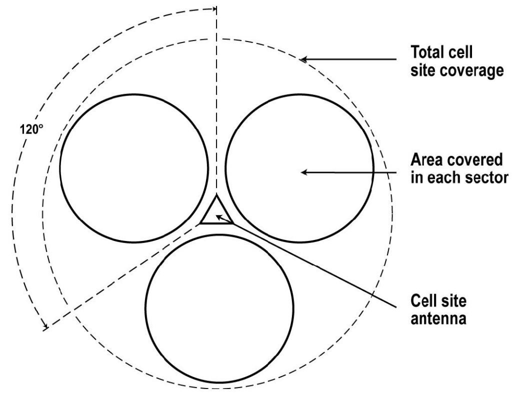
Access and Duplexing

Frequency Sharing

By allowing multiple users to share rare and expensive spectrum, carriers can make more money with more subscribers.

The basic frequency sharing concept is called frequency reuse. Many cell phone base stations within a given city or area share the same frequencies. By controlling base station spacing, transmitter power, antenna height and radiation patterns, base stations can operate on the same frequency without interfering with one another.

Sectorized cell sites with directional antennas permit more frequency reuse to further increase the base station's subscriber capacity.

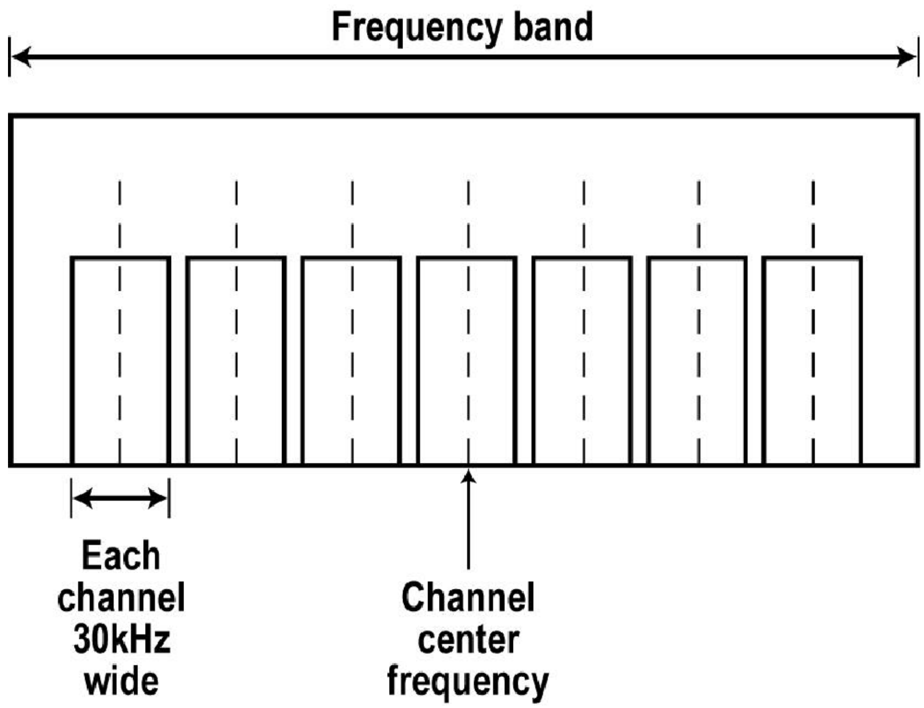


Access Methods

Access methods refer to how multiple users can share existing spectrum space. Access methods are ways of multiplexing many users into the same channel.

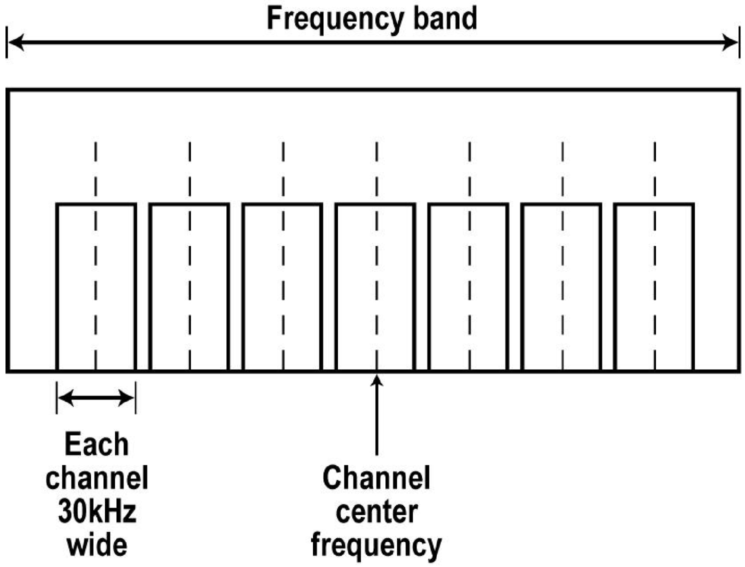
The four basic types of access are frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and spatial division multiple access (SDMA).

Frequency Division Multiple Access (FDMA)



Frequency division multiple access (FDMA) uses a large bandwidth of spectrum and divides it up into smaller bandwidth segments called channels. The channel is designated by its center frequency or a specially assigned number.

FDMA



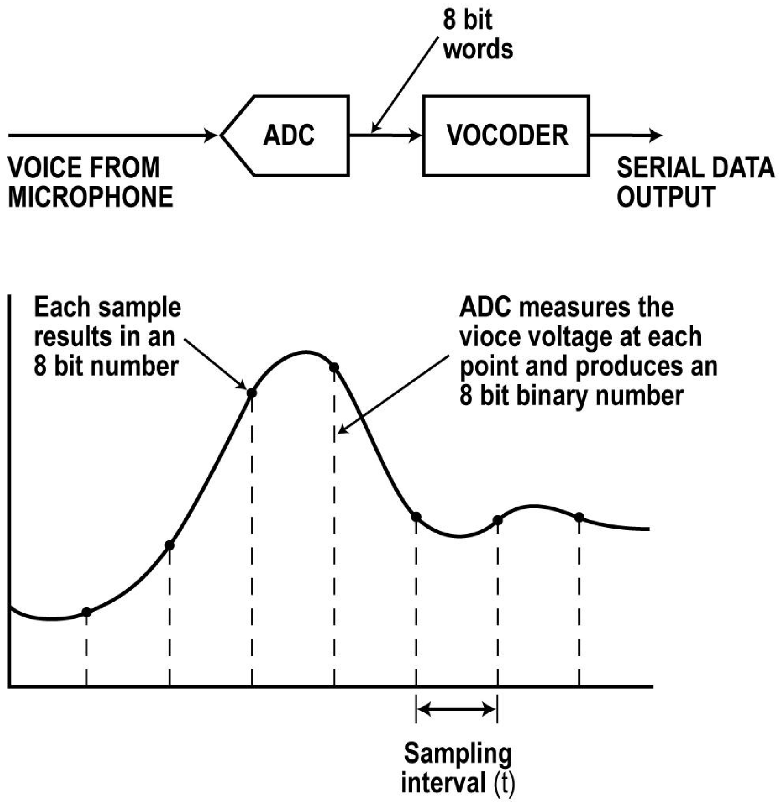
The figure shows a block of cell phone spectrum and how it has been divided into multiple 30 kHz channels. Each channel can hold one phone call, either uplink or downlink.

Other channel widths may be 50 kHz, 200 kHz, 1.25 MHz, or 5 MHz wide.

Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) uses a single channel of bandwidth but allows multiple subscribers to use it on a time shared basis.

TDMA is a digital technique that requires the voice signals to be in digital form. One way to do this is shown here.

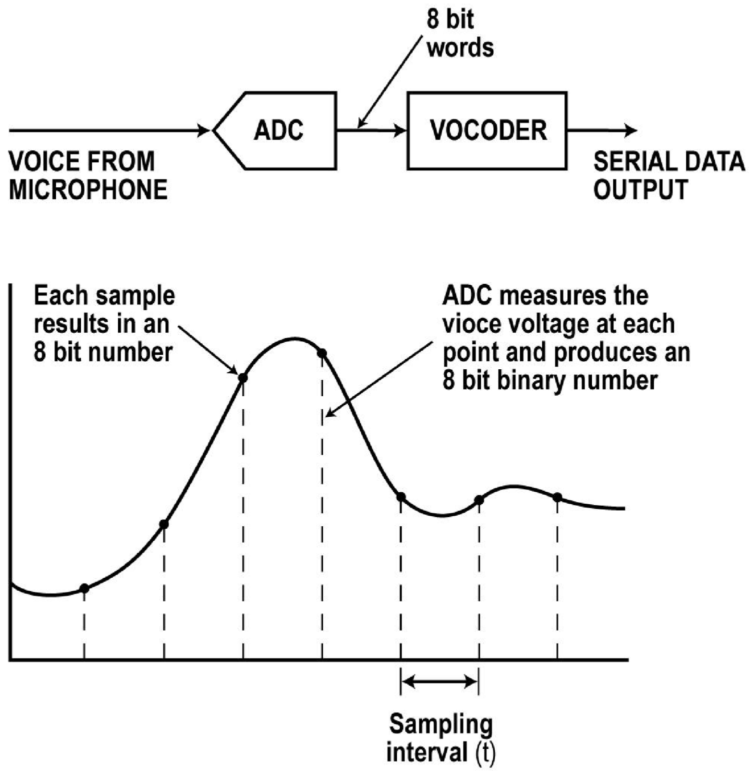


$$\text{Sampling rate} = \frac{1}{t}$$

$$\text{Sampling rate} = \frac{1}{125\mu s} = \frac{1}{125 \times 10^{-6}} = 8\text{kHz}$$

TDMA: ADC

The voice signal is digitized by an analog-to-digital to converter (ADC) by sampling the signal periodically, measuring the sample voltage and translating it into a stream of proportional binary numbers. A typical word length is 8-bits.



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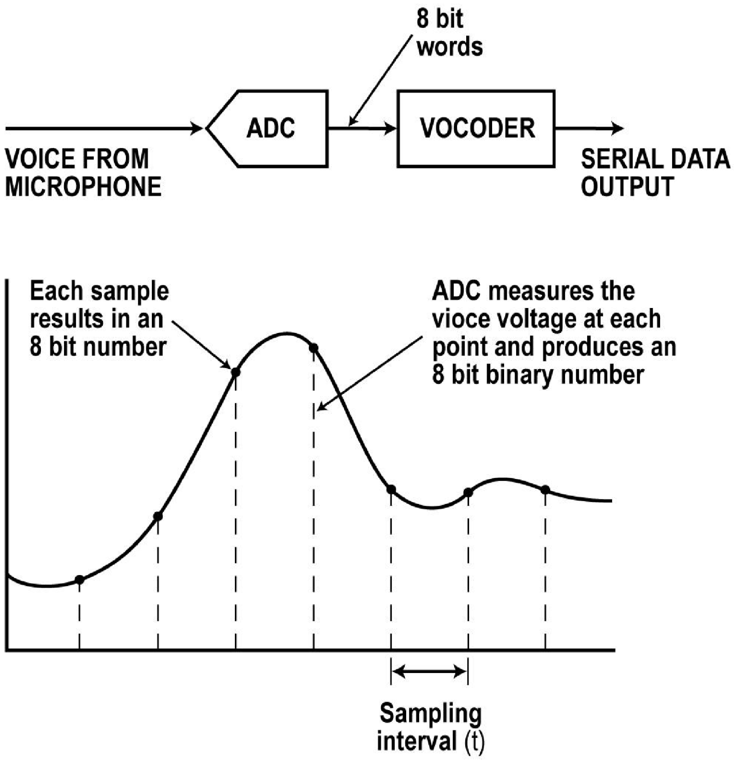
TDMA: Sampling Rate

The sampling rate must be high enough so that all the information is retained. It must be more than two times the highest frequency in the voice signal.

For example, if the highest voice frequency to be transmitted is 3.5 kHz, then the sampling rate must be 2 x 3.5 = 7 kHz.

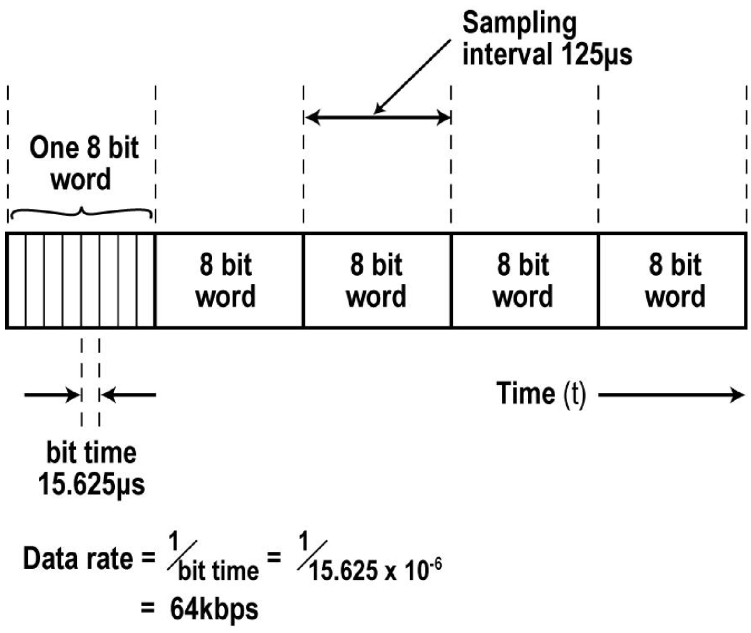
Typically the sampling rate is even higher. 8 kHz is common for voice signals.



Sampling rate = $1/t$

Sampling rate = $1/125\mu s$ = $1/125 \times 10^{-6}$ = 8kHz

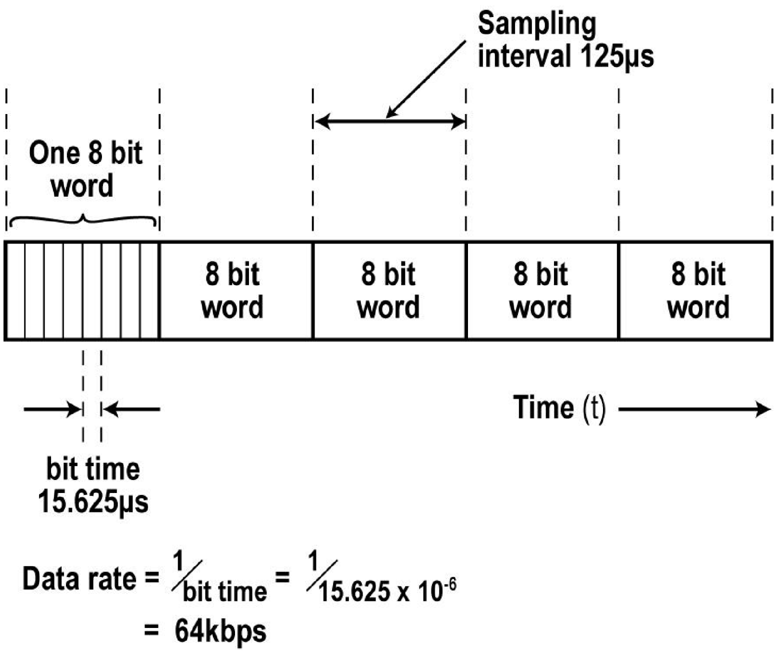
TDMA: Conversion



The multiple 8-bit words representing the voice can then be transmitted by converting them to serial format. They are then sent by radio one bit at a time, one word at a time.

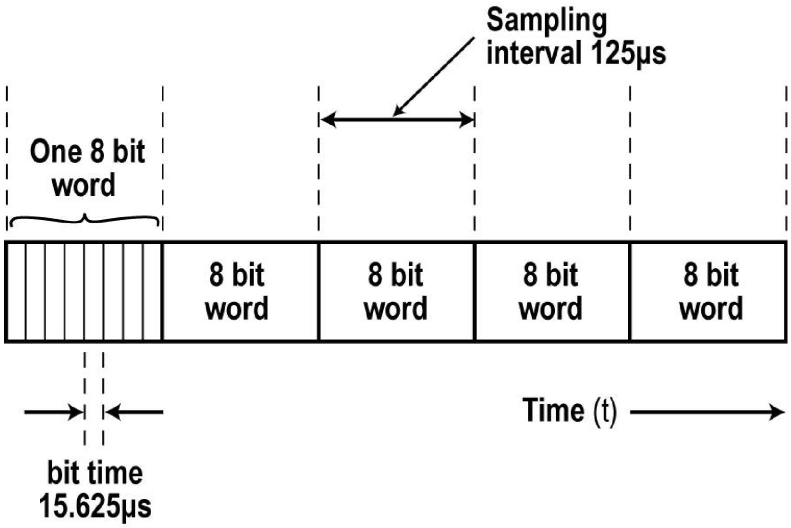
This form of transmission is known as pulse code modulation (PCM).

TDMA: Serial Data Rate



If each sample of the ADC occurs at an 8 kHz rate or every 125 microseconds, then each bit occupies a time of 125/8 = 15.625 microsecond. A bit time of 15.625 microsecond translates into a serial data rate of 1/15.625 x 10^{-6} = 64 kilobits per second (kbps).

TDMA: Vocoding



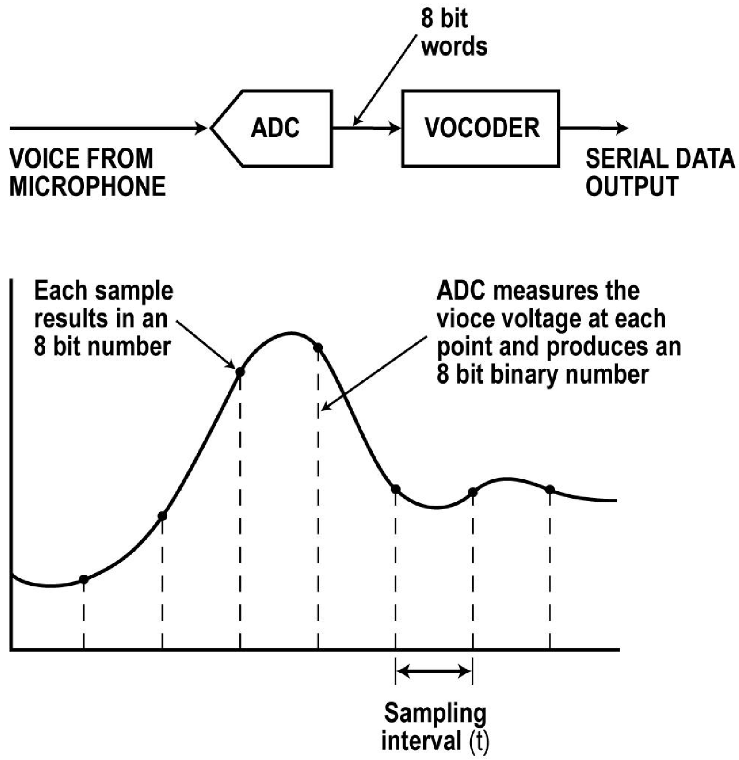
$$\text{Data rate} = \frac{1}{\text{bit time}} = \frac{1}{15.625 \times 10^{-6}} = 64\text{kbps}$$

It takes a minimum bandwidth of about 64 kHz to transmit a 64 kbps digital signal. Such a bandwidth is very wide and wasteful of spectrum. Therefore, a technique called vocoding is used after the ADC to compress the data rate and bandwidth.

Vocoding

Vocoding is the process of taking a fast serial data signal and compressing it so that it uses much less bandwidth.

A vocoder is the circuit that compresses the data. It uses digital techniques in the form of mathematical algorithms processed in a microprocessor to reduce the number of bits needed to accurately represent and reproduce the voice signal.



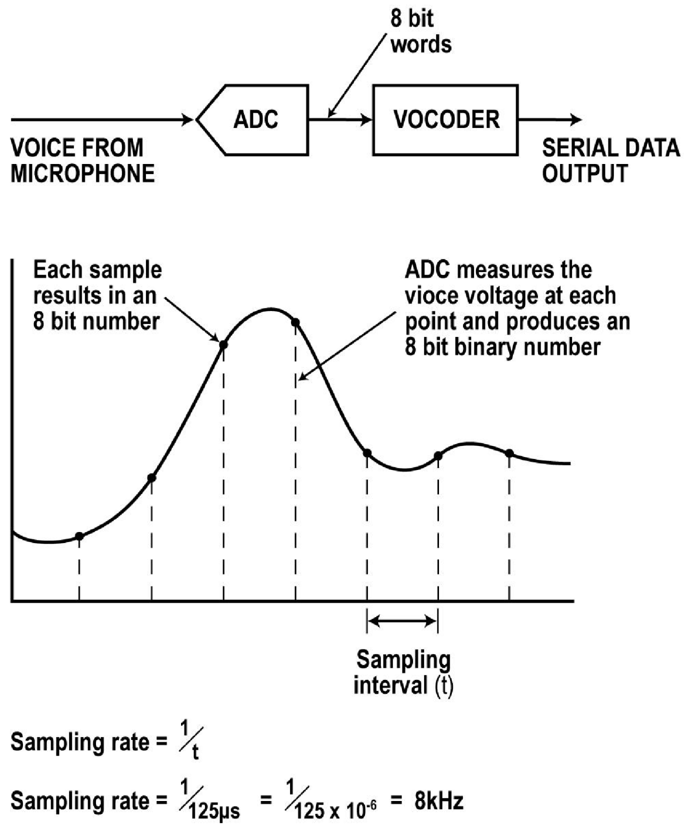
Sampling rate = $1/t$

Sampling rate = $1/125\mu s$ = $1/(125 \times 10^{-6})$ = 8kHz

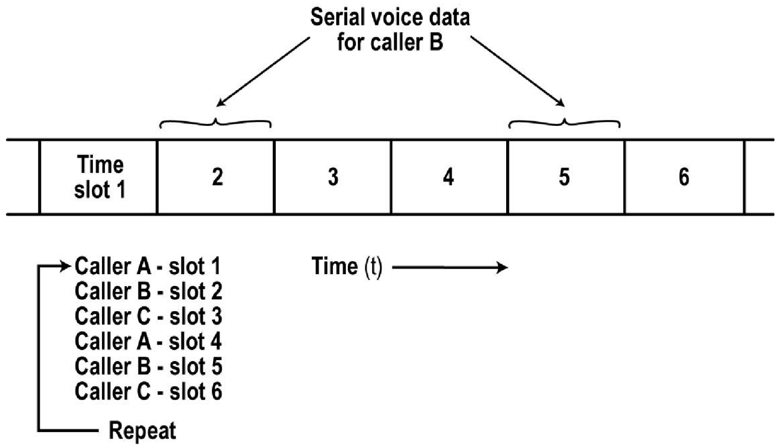
Codec

Vocoders produce output data rates of from 1 kbps to 13 kbps. Rates of 8 kbps and 13 kbps are the most common. This low rate makes the channel bandwidth smaller.

The combination of the ADC and the vocoder is usually called a codec. The vocoding is usually performed by a digital signal processor (DSP) in modern digital cell phones.



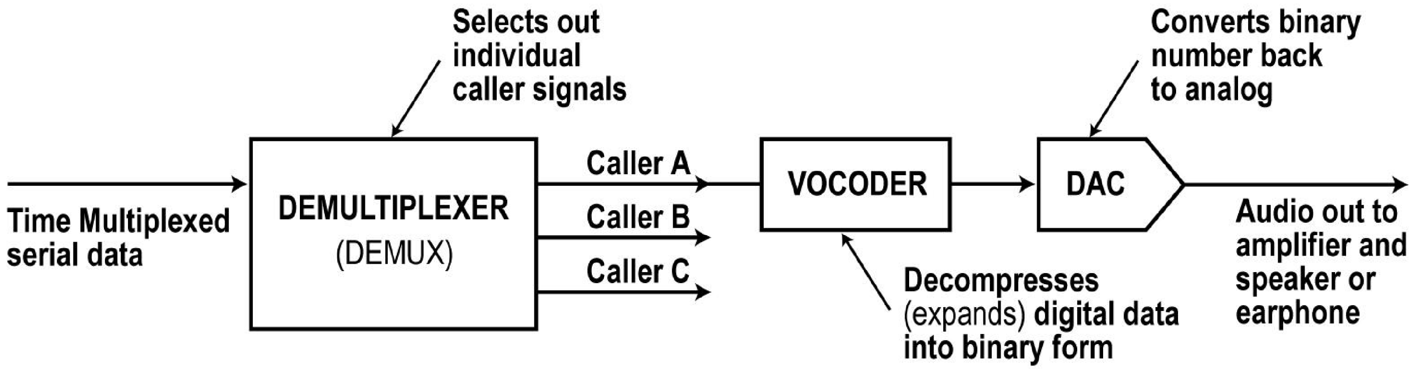
TDMA Format



TDMA allows more than one user to use the same frequency by transmitting the serial digital data representing multiple voices by sending one word from one voice signal followed by a word from a second voice signal the followed by a third and so on. For three voice signals, the transmission would look like that shown here.

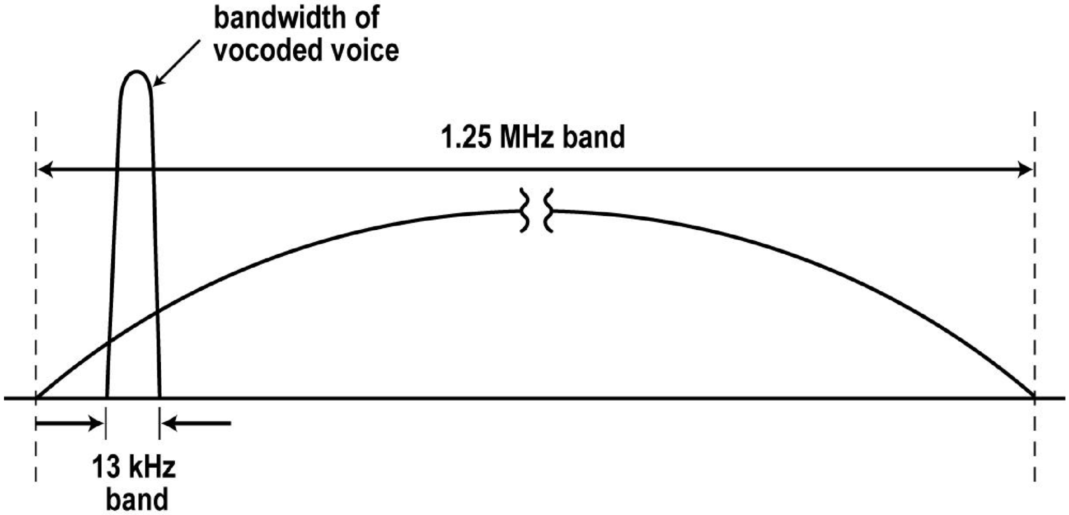
Since the binary numbers for each caller are occurring very fast, the human ear cannot tell that the signal has been segmented and transmitted in pieces at high speed.

TDMA: Digital-to-Analog



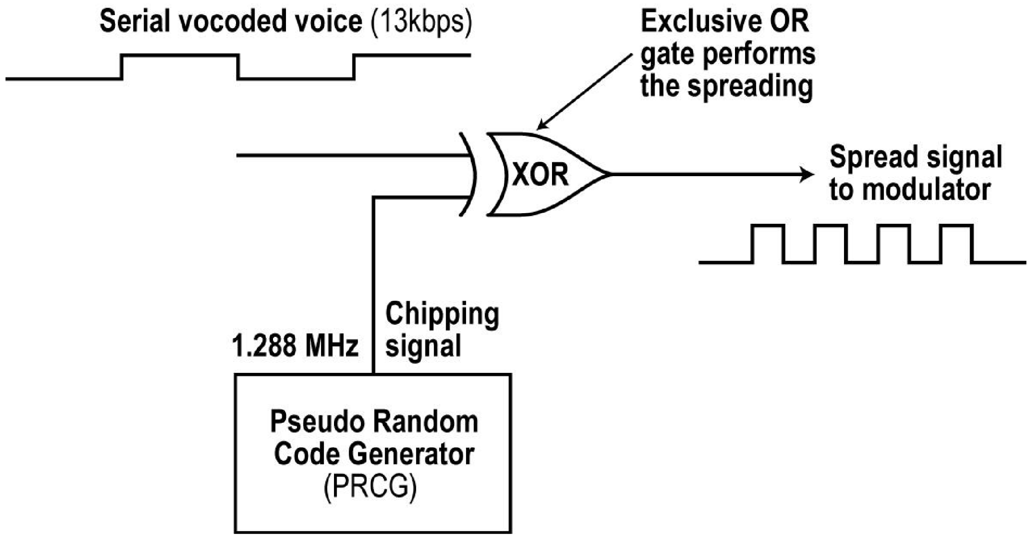
At the receiving end, a demultiplexer sorts out the individual voice signals, reassembles them in order then uses a vocoder to recreate the original voice data. Then a digital-to-analog converter (DAC) is used to translate the digital data back into the original voice signal.

Code Division Multiple Access (CDMA)



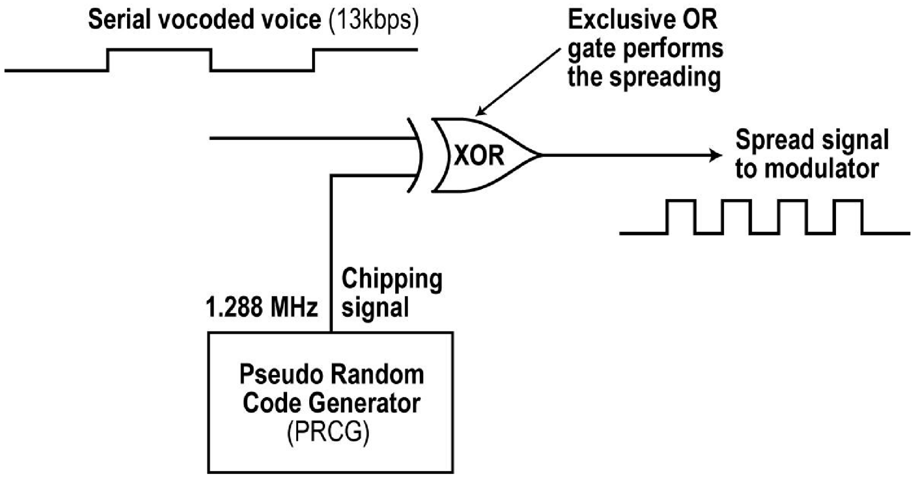
Code division multiple access (CDMA) is a form of digital transmission known as spread spectrum. Spread spectrum is a technique for taking a digital signal and modifying it so that it occupies a very wide bandwidth. For example, a digital voice signal that has been vocoded into a 13 kbps signal could be transmitted in a bandwidth of about 13 kHz. However, in spread spectrum, it is spread over a wider bandwidth channel such as 1.25 MHz.

CDMA: Direct Sequence Spectrum Signal



Typically the serial digital voice signal is mixed with a high frequency “chipping” signal with a unique code developed by a pseudo random code generator. The result is a much higher frequency serial digital signal that occupies a very wide bandwidth. The resulting signal is called direct sequence spread spectrum (DSSS) signal. The 1.228 Mbps exclusive OR (XOR) output can be transmitted in a 1.25 MHz wide channel.

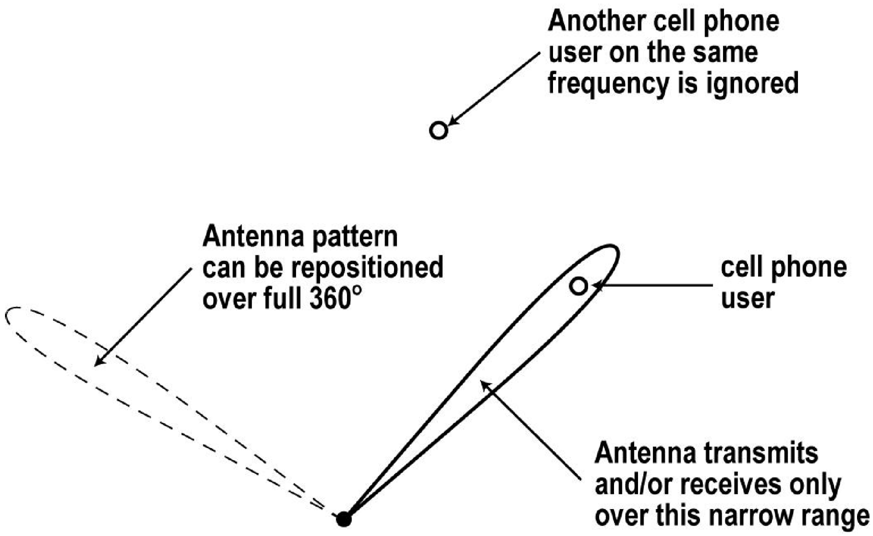
CDMA: Transmission



Each spread signal modulates the transmitter and the transmitter transmits in the same 1.25 MHz band simultaneously. Multiple spread signals occurring at the same time create a random jumble in the channel.

At the receiver, all of the signals that are mixed together appear as random noise. However, if the receiver knows the unique code assigned to one signal, a correlation circuit selects it out and recovers it for translation back to analog voice.

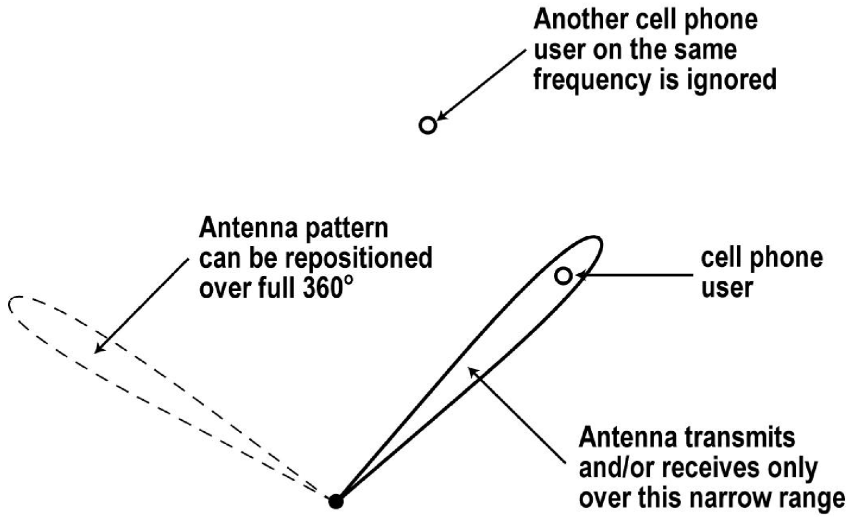
Spatial Division Multiple Access (SDMA)



Spatial division multiple access (SDMA) is a newer access method based on the use of highly directional antennas to precisely pin-point a cell phone or other wireless device while ignoring all others.

Multiple users can share the same frequency bands. Since the antennas have a very narrow range over which they will transmit or receive signals, they do not interfere with one another.

SDMA: Directional Antennas



SDMA is not yet widely used yet but has been deployed in wireless local area networks (WLANs). As cell phone base stations get retrofitted with the newer, more directional antennas, it will be deployed.

Antennas that can select a desired signal are called smart antennas or adaptive arrays.

Duplexing

Duplexing refers to two-way communications. Half duplex means alternating transmit and receive operations as in typical two-way mobile, marine, aircraft, and CB radio.

Full duplex means simultaneous two-way communications where each party can send and receive simultaneously. All phones are full duplex.

There are two types of duplex: frequency division duplex (FDD) and time division duplex (TDD).

Comparing FDD and TDD

In frequency division duplex (FDD), two separate frequencies are used, one for transmit and another for receive. The transmit and receive frequencies are far enough apart so that they do not interfere with one another in the cell phone or at the base station.

With time division duplex (TDD), a single channel is used for both send and receive but the transmit and receive signals are interleaved or alternated. TDD requires the signals to be in serial digital format. With fast enough sampling and signaling, a person cannot tell that the voice signals has been sampled and time multiplexed.

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